The availability of large, inexpensive supplies of electricity is important to the development of a nation. Without electricity, industry would grind to a halt, communications would cease, and our food supply would be seriously affected. The utilization of electric current allows us to enjoy our present standard of living. How is electric current controlled? What is involved in the design of high voltage transmission lines that allow current to flow with a minimum of energy loss?

Electric Currents

Chapter 23

Goal: You will gain an understanding of electric current, circuits, and the transfer of energy by means of current electricity.

The most important aspect of electricity is its ability to transfer energy. The large amounts of natural potential and kinetic energy possessed by resources such as Niagara Falls are of little use to an industrial complex one hundred kilometers away unless that energy can be transferred efficiently. Electricity provides the means to transfer large quantities of energy great distances with little loss.

At the industrial site, electric energy can be converted into other forms of energy, such as kinetic, sound, light, and thermal energy. Devices that make these conversions are very important in our everyday lives. Motors, loudspeakers, lamps, television sets, heaters, and air conditioners are examples of common devices that convert electric energy into another form of energy.

23:1 Producing Electric Current

Two conductors, *A* and *B*, in Figure 23-1, are at different potentials and connected by a third conductor, *C*. A flow of electrons occurs from the higher potential, *B*, to the lower potential, *A*. This electron flow is an **electric current**. The flow will stop as soon as the potentials become equal. The only way to maintain the electric current is to pump electrons from conductor *A* back to conductor *B*. The pumping will increase the potential energy of the electrons. Therefore, the electron pump requires energy. There are several devices available that can convert some other form of energy into electric energy. A voltaic or galvanic cell (a common dry cell) converts chemical energy to electric energy. Several cells connected together are called a **battery**. A **photovoltaic cell**, or solar cell, changes light energy into electric energy. A generator converts kinetic energy into electric energy.

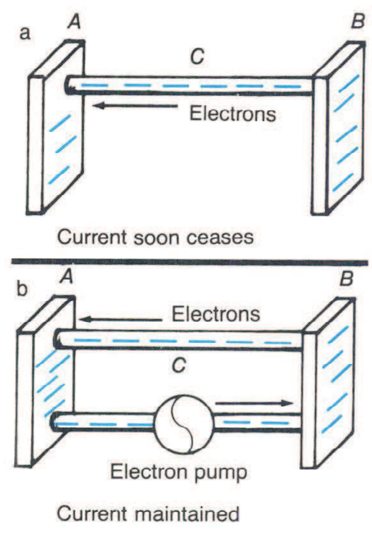

FIGURE 23-1. Electrons flow from the negative to positive plate (a). A generator (b) pumps electrons back to the negative plate allowing current to continue to flow.

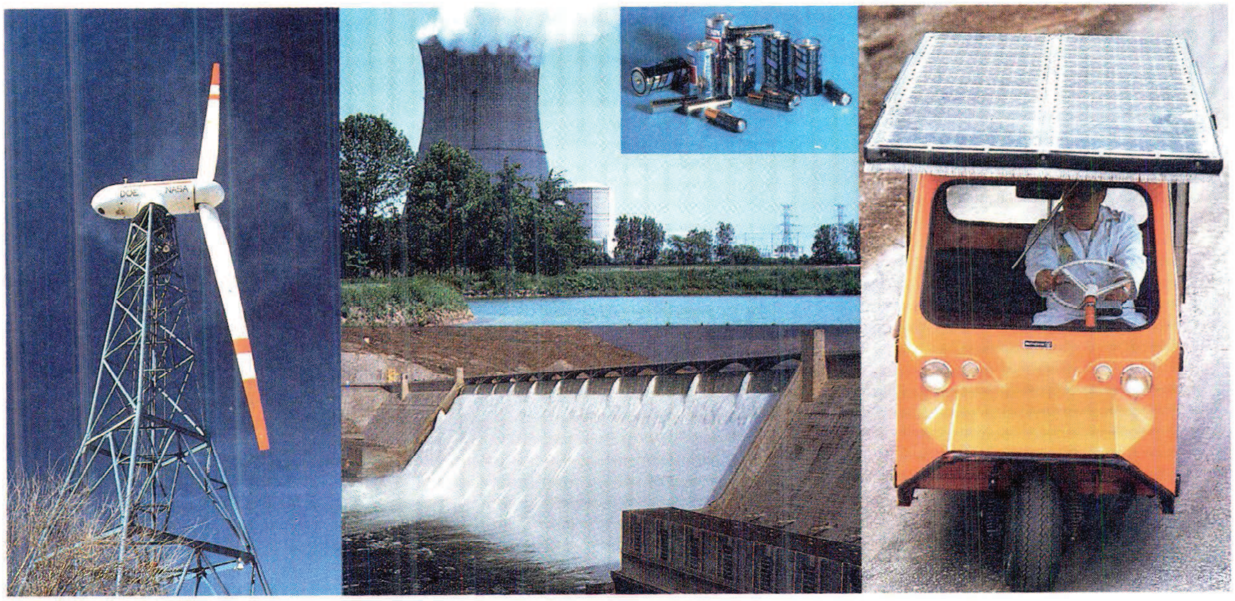

FIGURE 23-2. Sources of electric energy include chemical, solar, hydrodynamic, wind, and nuclear energies.

23:2 Current in Electric Circuits

Electrons flow around a closed loop called a circuit.

An electric circuit is a closed loop. A circuit consists of an electron pump, which increases the potential of the electrons, connected to a device that reduces the potential of the electrons. As the potential of the electron is reduced, the work done by the electric charge (qV) can be converted into another form of energy. A motor can convert electric energy to kinetic energy. A lamp can change electric energy into light. A heater can convert electric energy into thermal energy.

Electrons are able to flow through all of these energy conversion devices. As they flow, the electrons lose electric potential. Any device that reduces the potential of electrons flowing through it is said to have resistance.

Current is produced by an electron pump that increases the potential of electrons. Batteries, generators, and photovoltaic cells are electron pumps.

The electron pump creates the flow of electrons or current. Consider a generator driven by a water wheel (Figure 23-3). The potential energy of the water is converted to kinetic energy as the water falls. This energy is converted to kinetic energy within the generator. This energy is used by the generator to remove electrons from wire B and add them to wire A, increasing the electric potential difference between B and A. Work is done raising the potential of the electrons ($W = qV$). This work came from the change in potential energy of the water. However, no generator is 100 percent efficient. Two percent of the kinetic energy put into most generators is converted into thermal energy rather than electric energy.

If the wires A and B are connected to a motor, the excess electrons in wire A flow through the wires in the motor. The electron flow continues through wire B back to the generator. A motor converts

electric energy to kinetic energy. Like generators, motors are not 100 percent efficient. Perhaps 10 percent of the electric energy is changed into thermal energy instead of kinetic energy.

The drop in potential energy of electrons in a motor creates kinetic energy.

The net change in potential of the electrons going completely around the circuit is zero. The potential increase produced by the generator equals the potential loss in the motor. The total amount of charge (number of electrons) in the circuit does not change. If one coulomb flows through the generator in one second, one coulomb will also flow through the motor in one second.

The net change in potential around a circuit is zero. Current is the same everywhere in a circuit.

If the difference in potential between the two wires is 120 V, the generator must do 120 J of work on each coulomb of charge that it transfers from the positive wire to the negative wire. Thus, every coulomb of charge that moves from the negative wire through the motor and then back to the positive wire delivers 120 J of energy to the motor. Note that electric energy serves as a way to transfer the initial potential energy of falling water to the kinetic energy of a turning motor.

23:3 The Ampere and Electric Power

The unit used for quantity of electric charge is the **coulomb**. Thus, the rate of flow of electric charge, or electric current (I), is measured in coulombs per second. A flow of one coulomb per second is called an **ampere**, A.

One ampere of current is the flow of one coulomb of charge each second.

$$1 \text{ C/s} = 1 \text{ A}$$

The ampere is named for the French scientist Andre Marie Ampere (1775-1836). An ammeter is a device that measures current.

Electric current is measured in amperes.

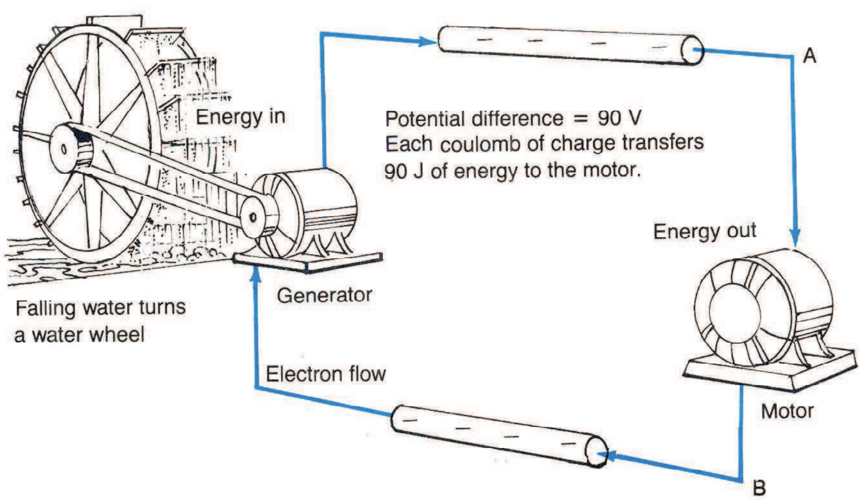

FIGURE 23-3. This diagram shows the production and use of electric current. Electric potential energy is converted to kinetic energy of the turning motor.

Suppose that the current through the motor of Figure 23-3 is 3.0 C/s (3.0 A). The potential difference of 120 V means that each coulomb of charge supplies the motor with 120 J of energy. The energy delivered to the motor per second is

$$(120 \text{ J/C})(3.0 \text{ C/s}) = 360 \text{ J/s} = 360 \text{ watts.}$$

Power consumed *(P)* is equal to potential difference *(V)* times current *(I)*. $P = VI$

The power rating of an electric device is found by multiplying the voltage V by the current I.

$$\boxed{P = VI}$$

EXAMPLE

Electric Power

A 6-V battery delivers 0.5 A of current to an electric motor connected across its terminals. **a.** What is the power rating of the motor? **b.** How much energy does the motor use in 5.0 min?

Given: $V = 6 \text{ V}$

Current $(I) = 0.5 \text{ A}$

$t = 5.0 \text{ min } (300 \text{ s})$

Unknowns: **a.** P **b.** W

Basic equation: **a.** $P = VI$ **b.** $P = \frac{W}{t}$

Solution: **a.** $P = VI$

$$= (6 \text{ V})(0.5 \text{ A}) = (6 \text{ J/}\cancel{\text{C}})(0.5\ \cancel{\text{C}}\text{/s}) = 3 \text{ J/s} = 3 \text{ W}$$

b. $P = \frac{W}{t}$

$W = Pt$

Energy is power times the time.

$= (3 \text{ W})(300 \text{ s})$

$= 900 \text{ J}$

Problems

1. 60 W

3. 960 W

5. 0.63A

1. The current through a light bulb connected across the terminals of a 120-V outlet is 0.5 A. At what rate does the bulb use electric energy?
2. A 12-V automobile battery causes a current of 2.0 A to flow through a lamp. What is the power rating of the lamp?
3. The current through a toaster connected to a 120-V source is 8.0 A. What is the power rating of the toaster?
4. A light bulb uses 1.2 A when connected across a 120-V source. What is the wattage of the bulb?
5. What current flows through a 75-W light bulb connected to a 120-V outlet?
6. The current through the starter motor of a car connected to a 12-V battery is 210 A. What electric energy is delivered to the starter in 10.0 s?

7. A flashlight bulb is connected across a 3.0-V difference in potential. The current through the lamp is 1.5 A.

a. What is the power rating of the lamp?

b. How much electric energy does the lamp convert in 11 min?

8. A lamp draws 0.50 A from a 120-V generator.

a. How much power does the generator deliver?

b. How much energy does the lamp convert in 5 minutes?

7. a. 4.5 W
b. 3.0×10^3 J

23:4 Ohm's Law

Almost every conductor offers **resistance** to an electric current. This resistance causes a potential difference to exist between the ends of a conductor when current passes through it. The German scientist Georg Simon Ohm (1787-1854) found that the ratio of the potential difference between the ends of the conductor and the current through it is constant for many materials.

This ratio is known as the resistance of a conductor. It is constant for any given conductor kept at a constant temperature. This relationship, known as Ohm's law, states that the current through a given conductor varies directly with the applied potential difference and inversely with the resistance.

$$I = \frac{V}{R}$$

The electric current, I, is in amperes. The potential difference, V, is in volts. The resistance of the conductor, R, is given in ohms. One ohm, 1 Ω, is the resistance that permits a current of 1 A to flow through a potential difference of 1 V.

Wires used to connect electric devices have very small resistances. One meter of a typical wire used in physics labs has a resistance of about 0.03 Ω. Wires used in house wiring offer as little as 0.004 Ω resistance for each meter of length. However, a device that is designed to have a specific resistance is called a resistor. Resistors are made of long, thin wires, graphite, or semiconductors.

Ohm's law states that a larger potential difference, or voltage, placed across a resistor causes a larger current through it. Ohm's law also says that if the current through a resistor is doubled, the drop in potential is also doubled. It follows that the voltage applied across the resistor would have to be doubled to obtain the increased current.

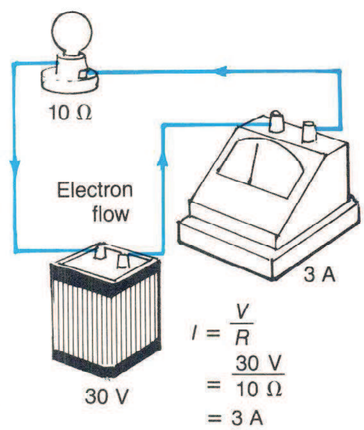

FIGURE 23-4. Ohm's law is illustrated in calculating the current between a potential difference of 30 volts and a resistance of 10 ohms.

In a conductor, the current flow is $I = V/R$, where V is the potential difference and R the resistance. This is called Ohm's law.

For a device that obeys Ohm's law, the resistance R is independent of the current.

According to Ohm's law, for a given resistance, the potential difference is proportional to the current flow.

EXAMPLE

Ohm's Law

What is the current through a 30-Ω resistance that has a potential difference of 120 V?

Given: $V = 120\text{ V}$
Resistance $(R) = 30\ \Omega$

Unknown: I

Basic equation: $I = \frac{V}{R}$

Solution: $I = \frac{V}{R}$

$= \frac{120\text{ V}}{30\ \Omega}$

$= 4\text{ A}$

Problems

9. 0.4 A

11. a. 200 Ω
b. 60 W

13. $2 \times 10^4\ \Omega$

9. An automobile headlight with a resistance of 30 Ω is placed across a 12-V battery. What is the current through the circuit?

10. A voltage of 75 V is placed across a 15-Ω resistor. What is the current through the resistor?

11. A lamp draws a current of 0.5 A when it is connected to a 120-V source.

a. What is the resistance of the lamp?
b. What is the power rating of the lamp?

12. A motor with an operating resistance of 32 Ω is connected to a voltage source. The current in the circuit is 3.8 A. What is the voltage of the source?

13. A transistor radio uses 2×10^{-4} A of current when it is operated by a 3-V battery. What is the resistance of the radio circuit?

14. A resistance of 60 Ω has a current of 0.4 A throughout it when it is connected to the terminals of a battery. What is the voltage of the battery?

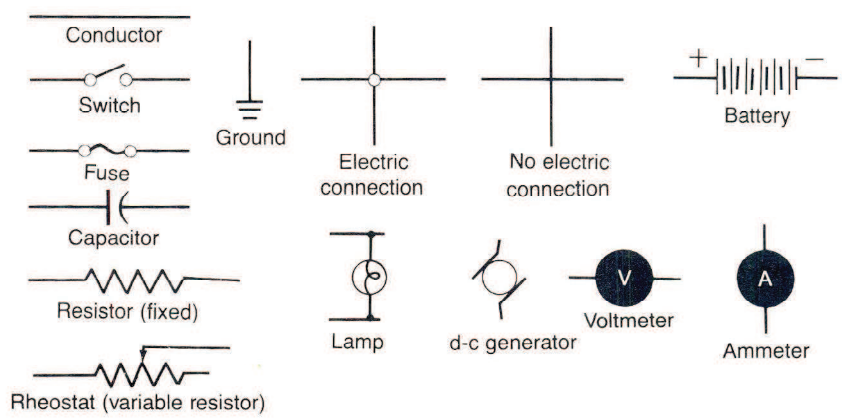

FIGURE 23-5. Electric circuit symbols.